Low Emittance Engineering – an Overview

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Engineering for Low Emittance
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OUTLINE

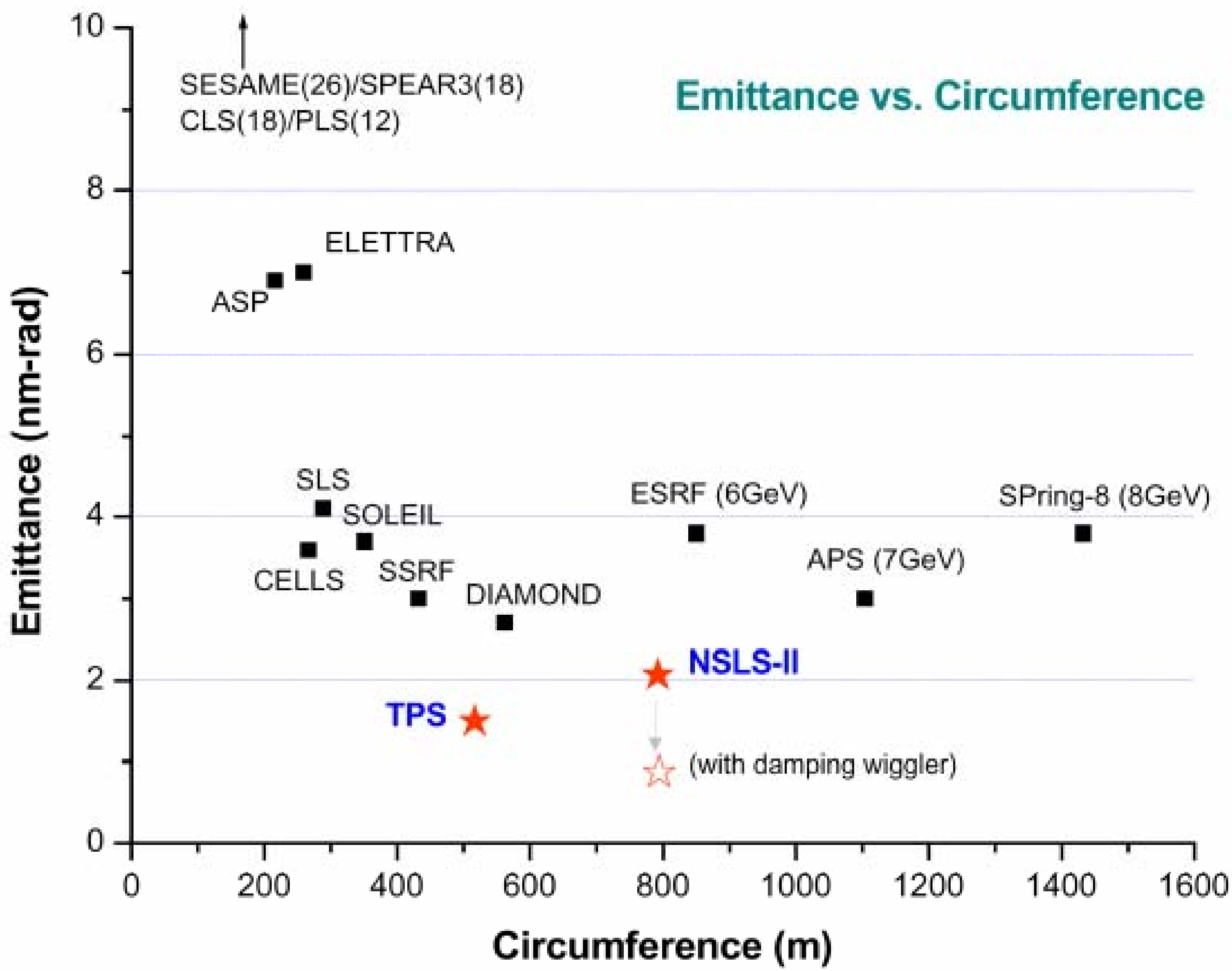
I. Introduction

II. Fine positioning

III. Temperature stabilization

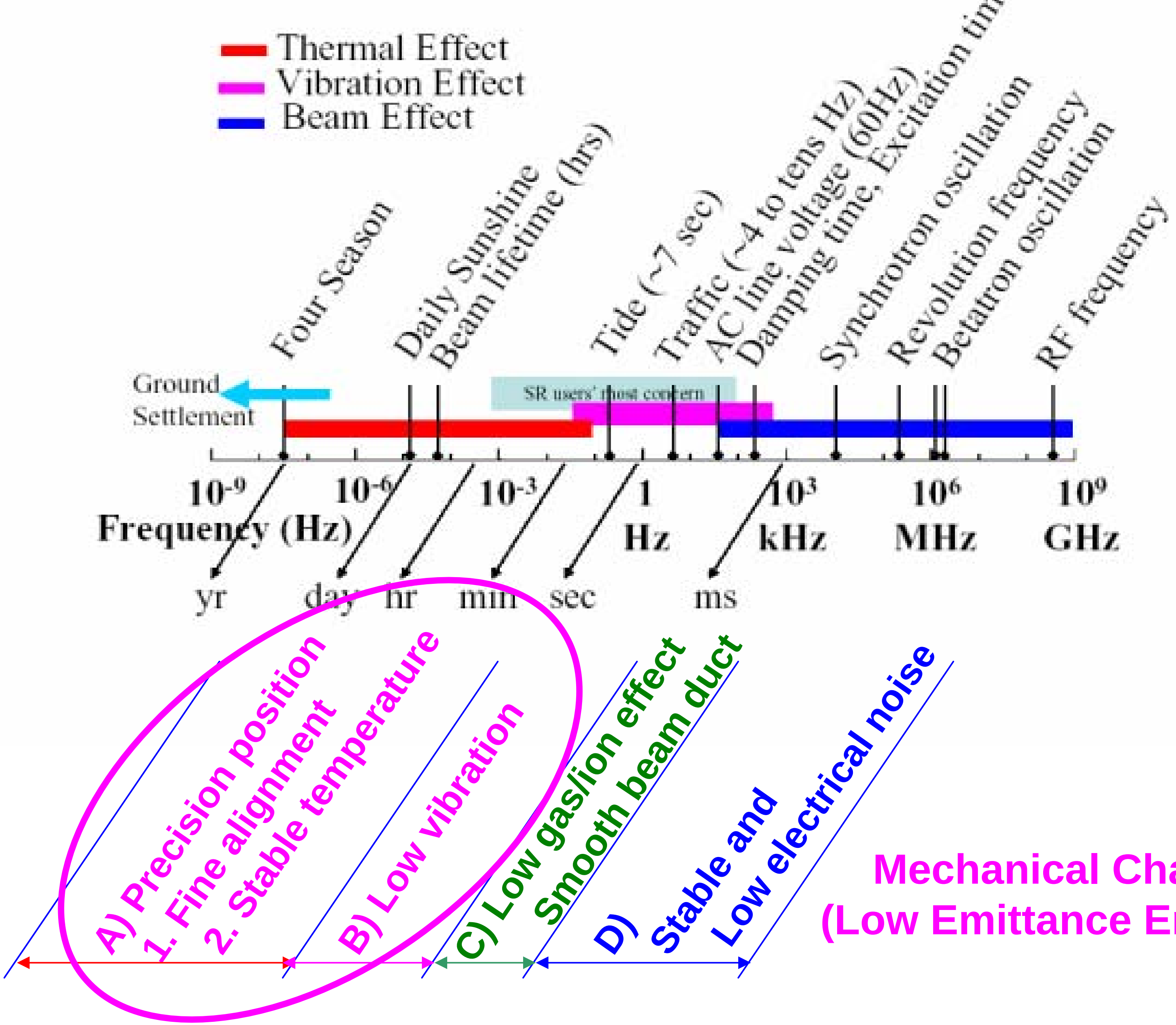
IV. Vibration suppression

V. Summary



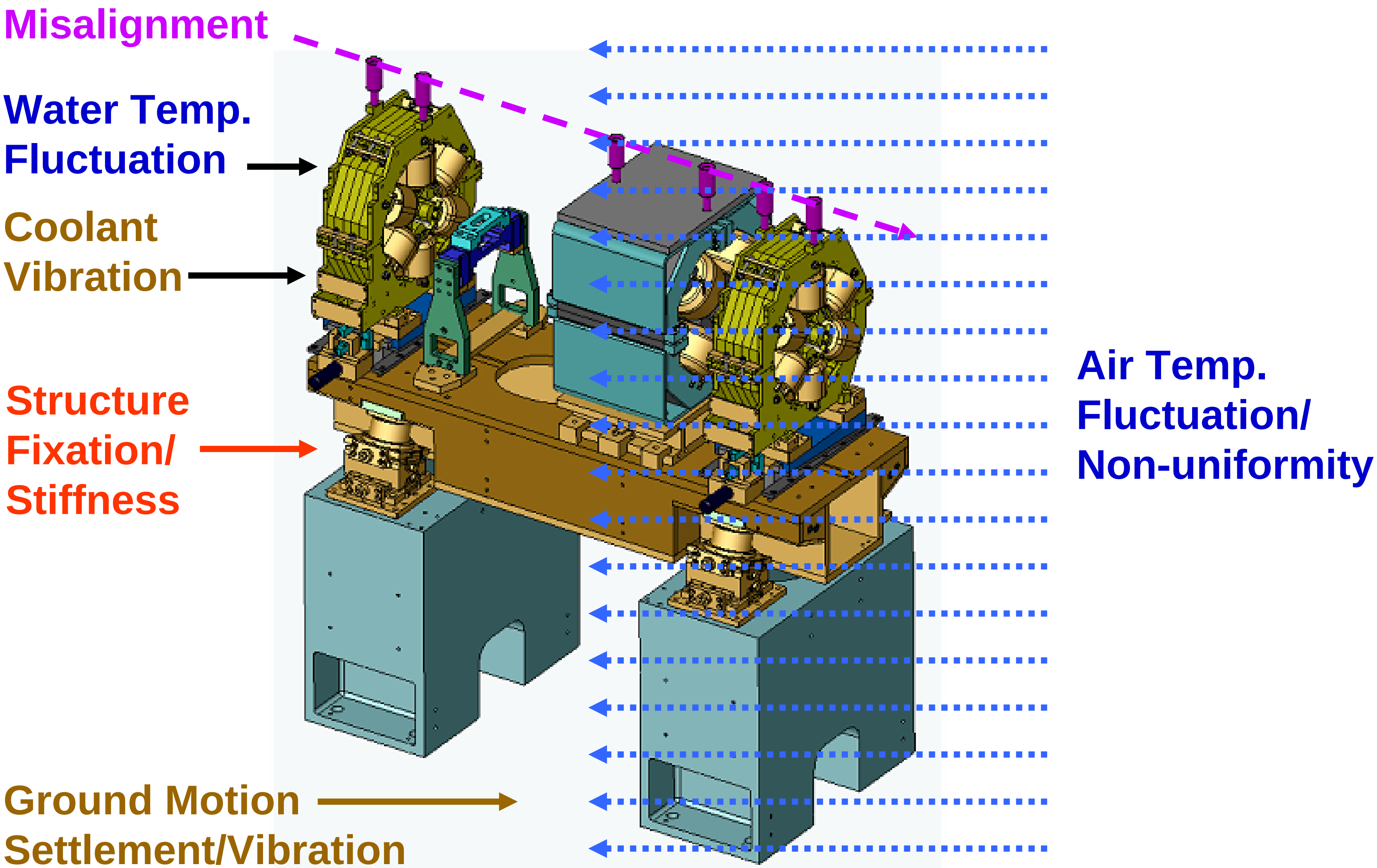
Emittance vs. Circumference
SESAME(26)/SPEAR3(18)
CLS(18)/PLS(12)
ELETTRA
ASP
SLS
SOLEIL
CELLS
SSRF
DIAMOND
ESRF (6GeV)
APS (7GeV)
SPring-8 (8GeV)
NSLS-II
TPS
(with damping wiggler)
Emittance (nm-rad)
Circumference (m)
0
2
4
6
8
10
200
400
600
800
1000
1200
1400
1600

Technology Challenges to Beam Stability

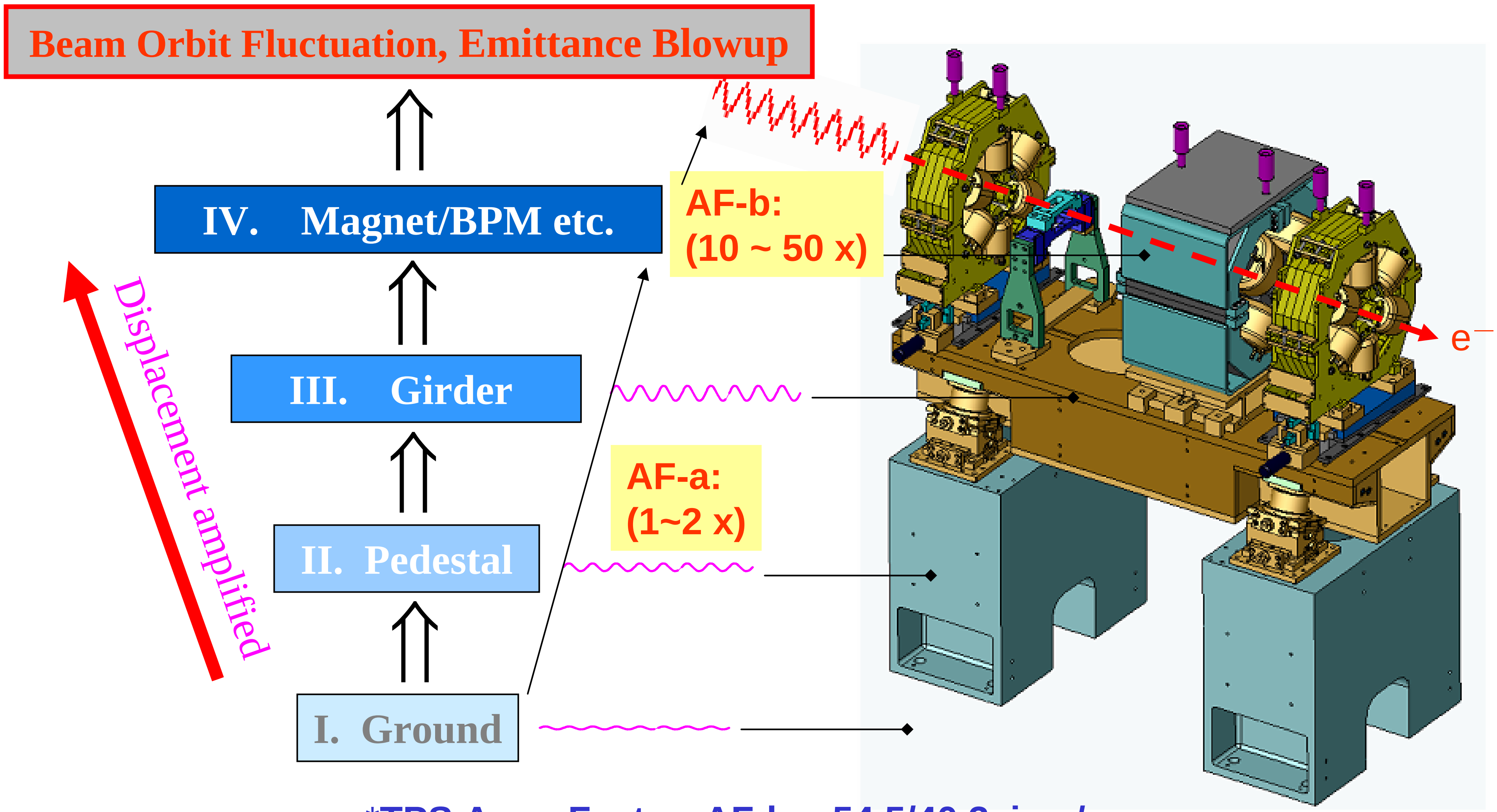


Mechanical Challenges
(Low Emittance Engineering)

Sources of Disturbance



Amplification Factors (AF)



*TPS Amp. Factor, AF-b = 54.5/40.3 in x/y rms
with girder grouping → 30.6/8.0 in x/y rms

II. Fine positioning

-- Aligning the magnets on the same girder

-- Leveling and alignment for the whole machine

-- Other concerns

$$A = \frac{\Delta x_{rms}}{\Delta q_{rms}}$$

$$A = \frac{\sqrt{\beta_{obs}}}{2\sqrt{2}\sin \pi \nu} \sqrt{\sum_i \beta_i (Kl_i)^2}$$

Δx_{rms} – beam displacement

Δq_{rms} – quadrupole displacement

Alignment and Stability Requirements

Alignment purpose → Small COD (within aperture)
→ 100 μm (30 μm/ on girder)

Stability purpose → Small photon intensity fluctuation (< 0.1%)
→ ~ 0.2 μm (0.05 ~ 0.1 σ_y) on magnet

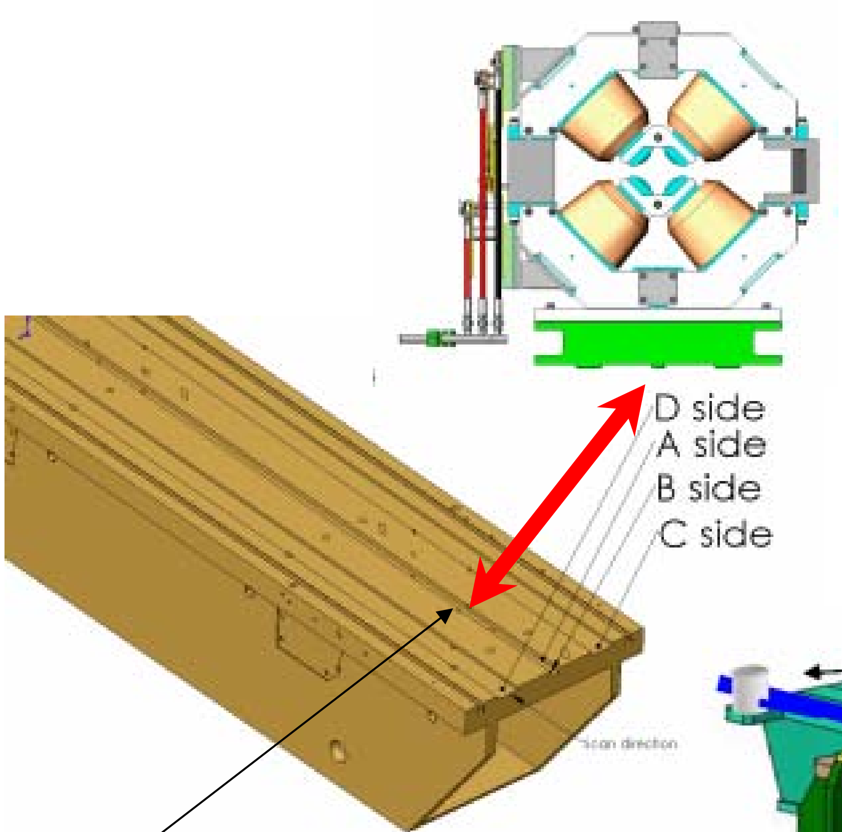
~ 0.2 μm ground vibration
➔ Structure Amplification Factor
AF-a = 1

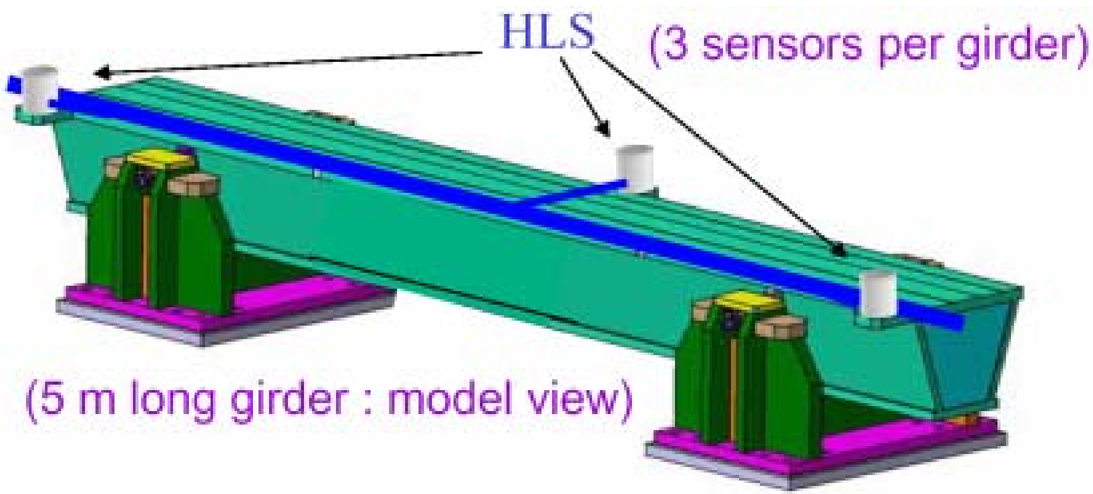
Table The alignment tolerances for the TPS

	x (mm)	y (mm)	s (mm)	x' (mrad)	y' (mrad)	s' (mrad)
Girder	0.1	0.1	0.2	0.07	0.07	0.1
Quadrupole w.r.t. girder	0.03	0.03	0.2	0.2	0.2	0.1
Sextupole w.r.t. girder	0.03	0.03	0.2	0.2	0.2	0.1
Dipole	0.5	0.5	0.5	0.5	0.5	0.2
BPM	0.1	0.1	-	-	-	-

Aligning the magnets on the same girder

References surfaces:
SLS, DLS, Soleil, TPS, etc.



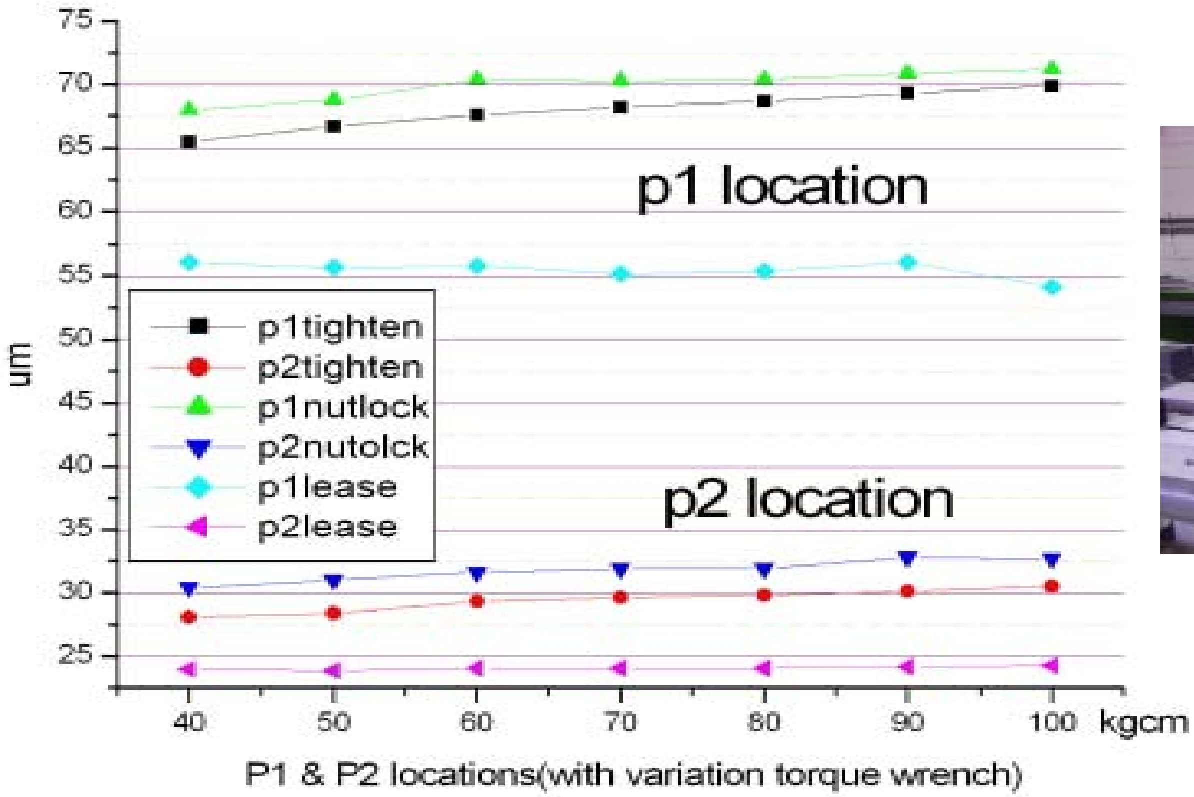


Magnets are fixed to the girder by matching the pre-machined reference surfaces at both the bottom of the magnets and the top of the girder.

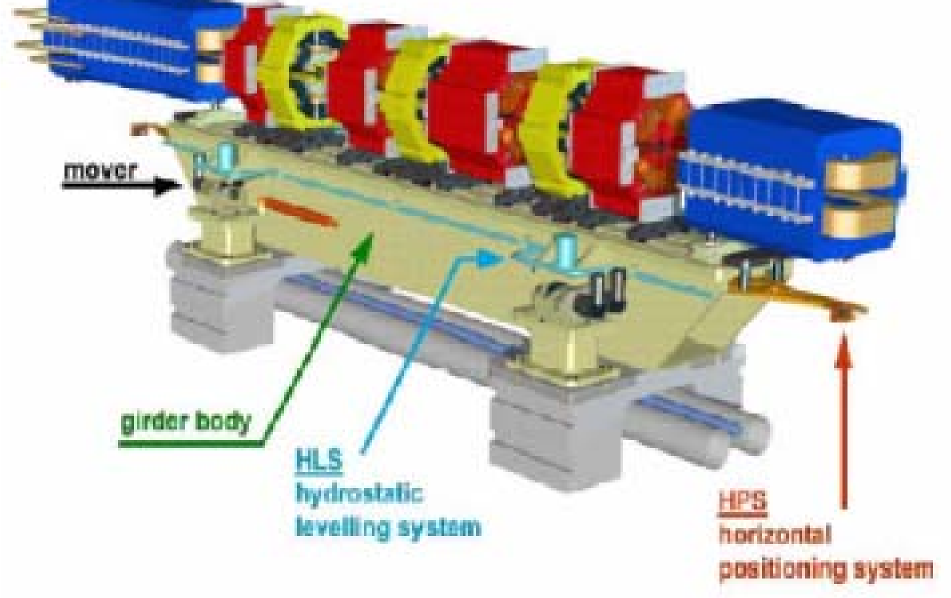
***Amp. factor without girder = 54.5/40.3 in x/y rms**
***Amp. factor With girder = 30.6/8.0 in x/y rms**

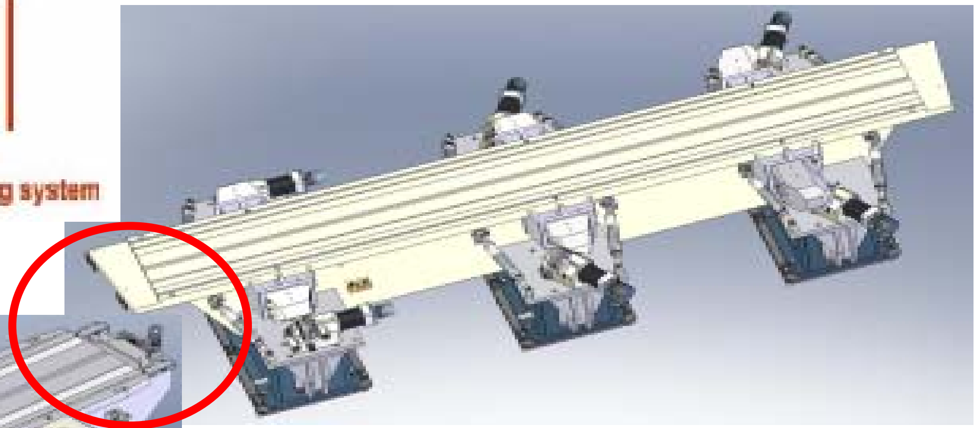
Magnet positioning accuracy

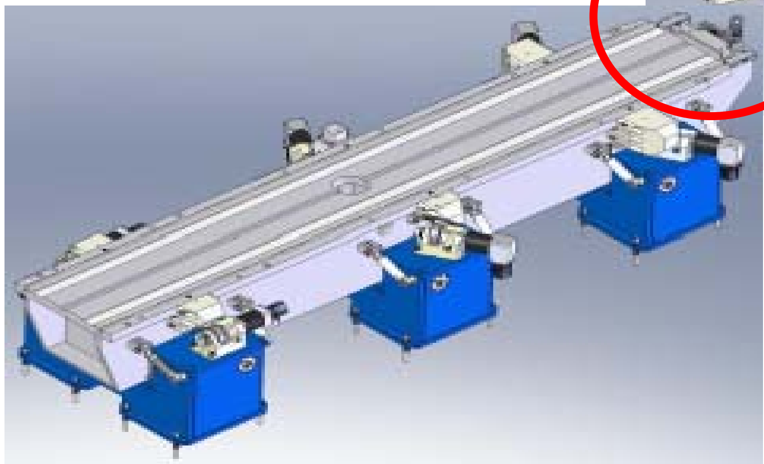
The accuracy of magnet positioning at the girder: $< \pm 2 \mu m$ per10 kg-cm tightening torque.



Touch Sensors & Leveling
Micron resolution



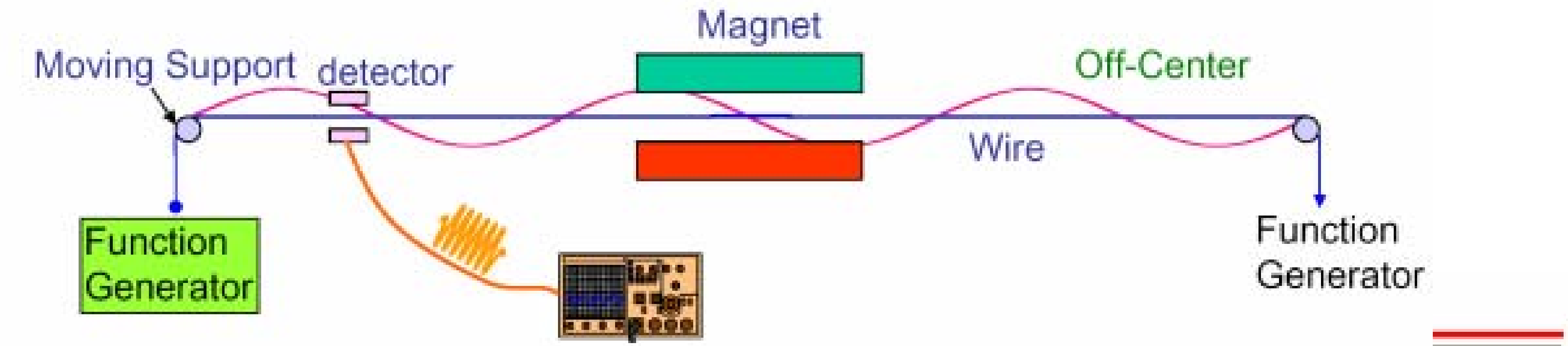


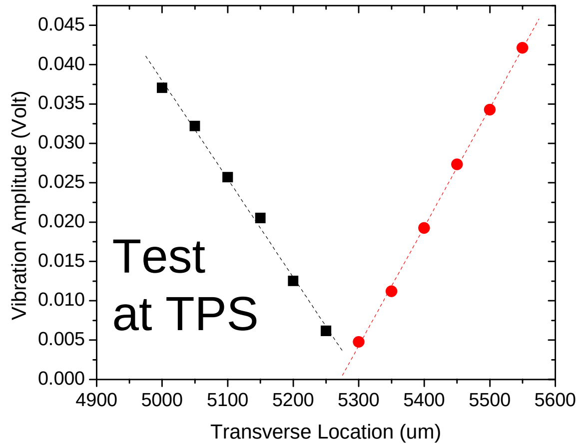


HLS: SLS, DLS, Soleil,, etc.
TPS: electronics leveling
+ touch sensors

Vibrating wire

Whether the mechanical center of a magnet is the same as the magnetic field center is always in doubt. → Vibrating Wire





A. Jain, NSLS-II Prototype Lattice Magnet Design Review, BNL, Jan.28-29, 2008.

The positioning error for quadrupoles : < 5 μ m.
For sextupoles: several factors could contribute to positioning errors.

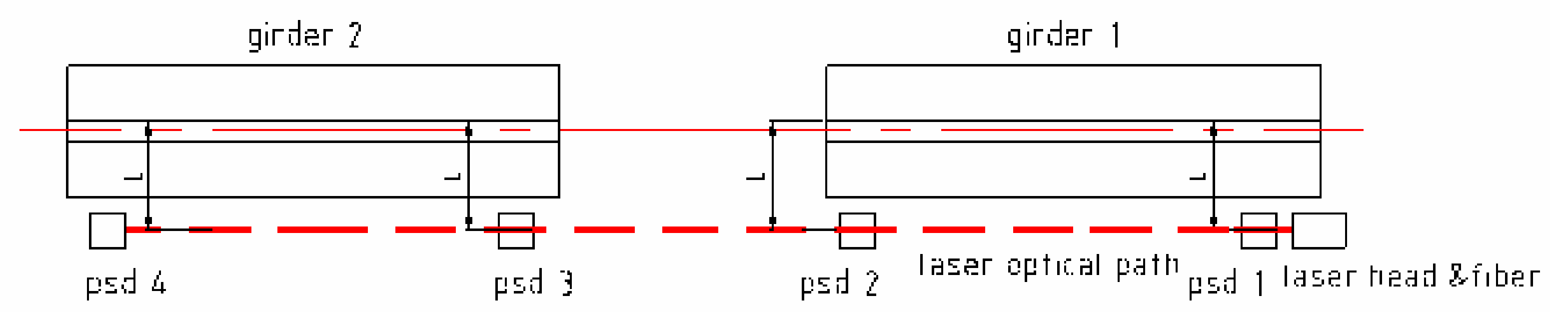
Girder to Girder Alignment

TPS:

1) adjacent girders in an arc section
→Touch sensors

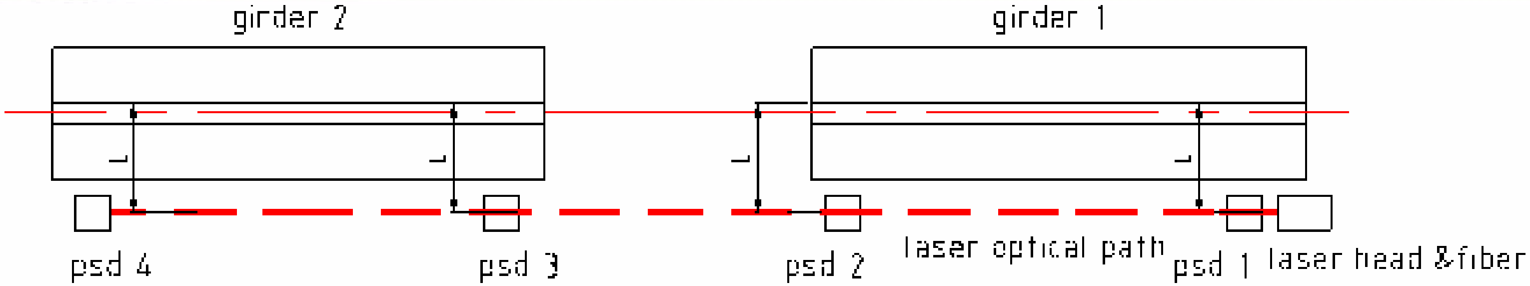
2) two girders at opposite sites of a long straight section
→ laser-based alignment system

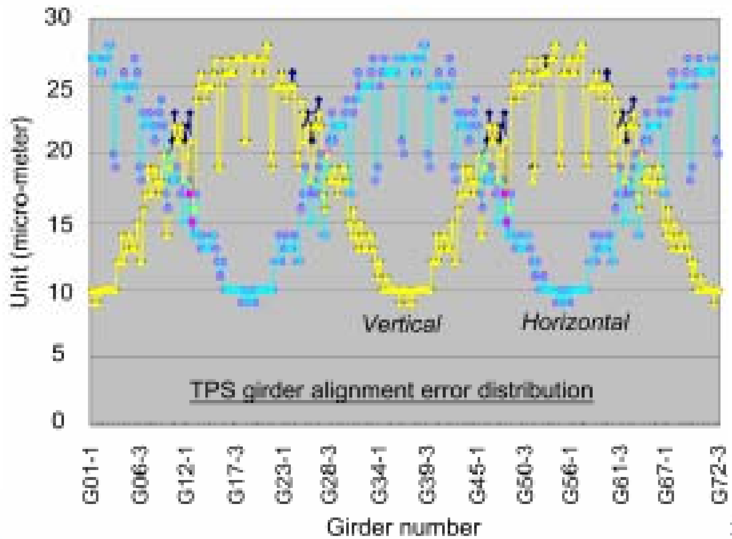
3) Simulation Results <30um/global

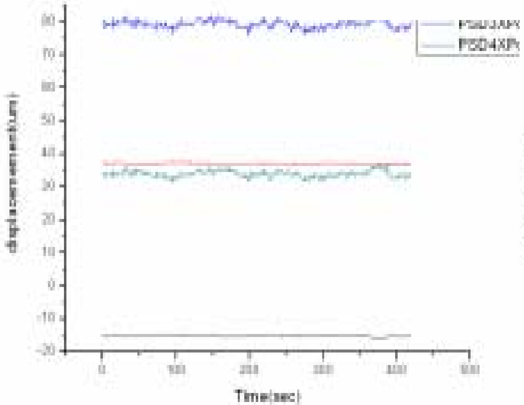


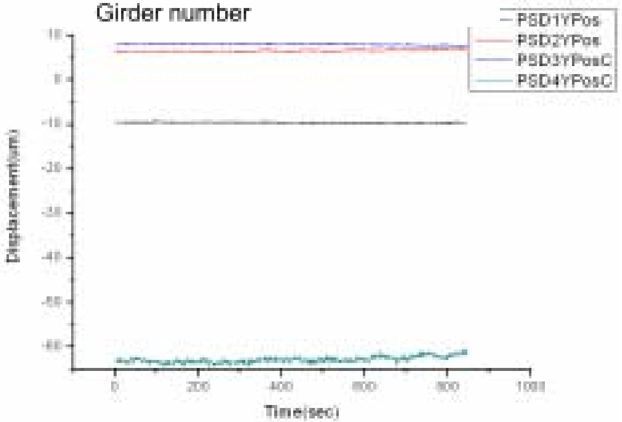
NSRRC

Girder to Girder Alignment

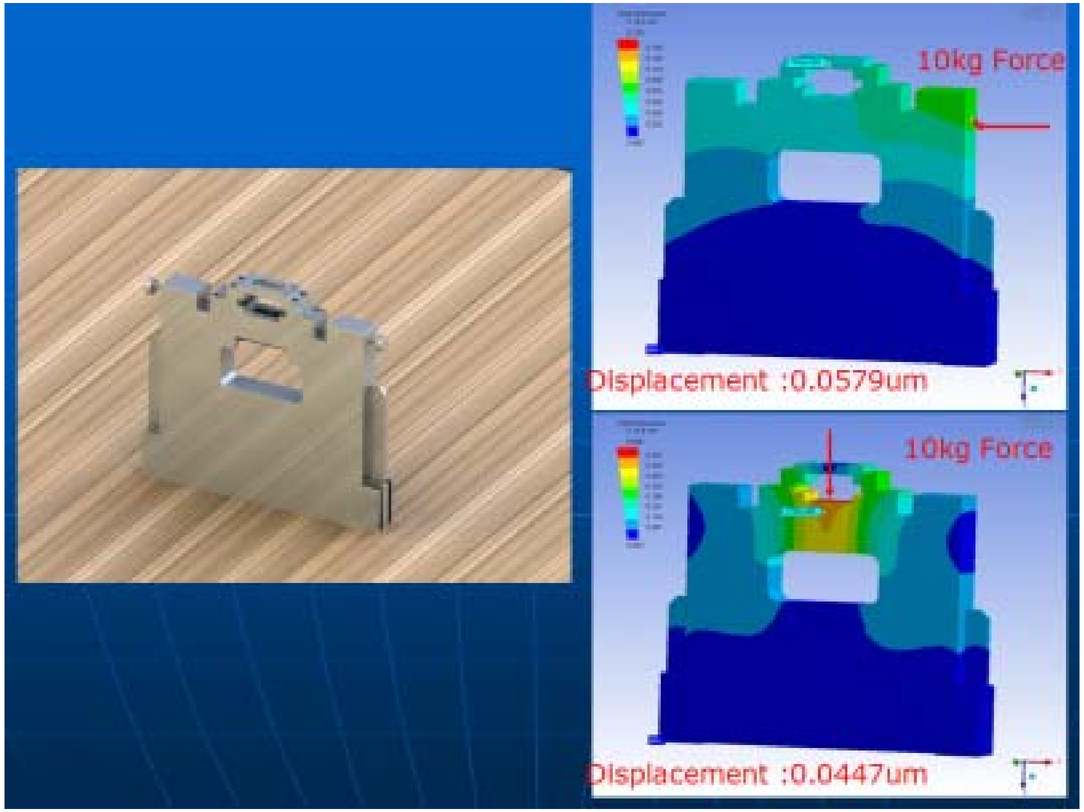








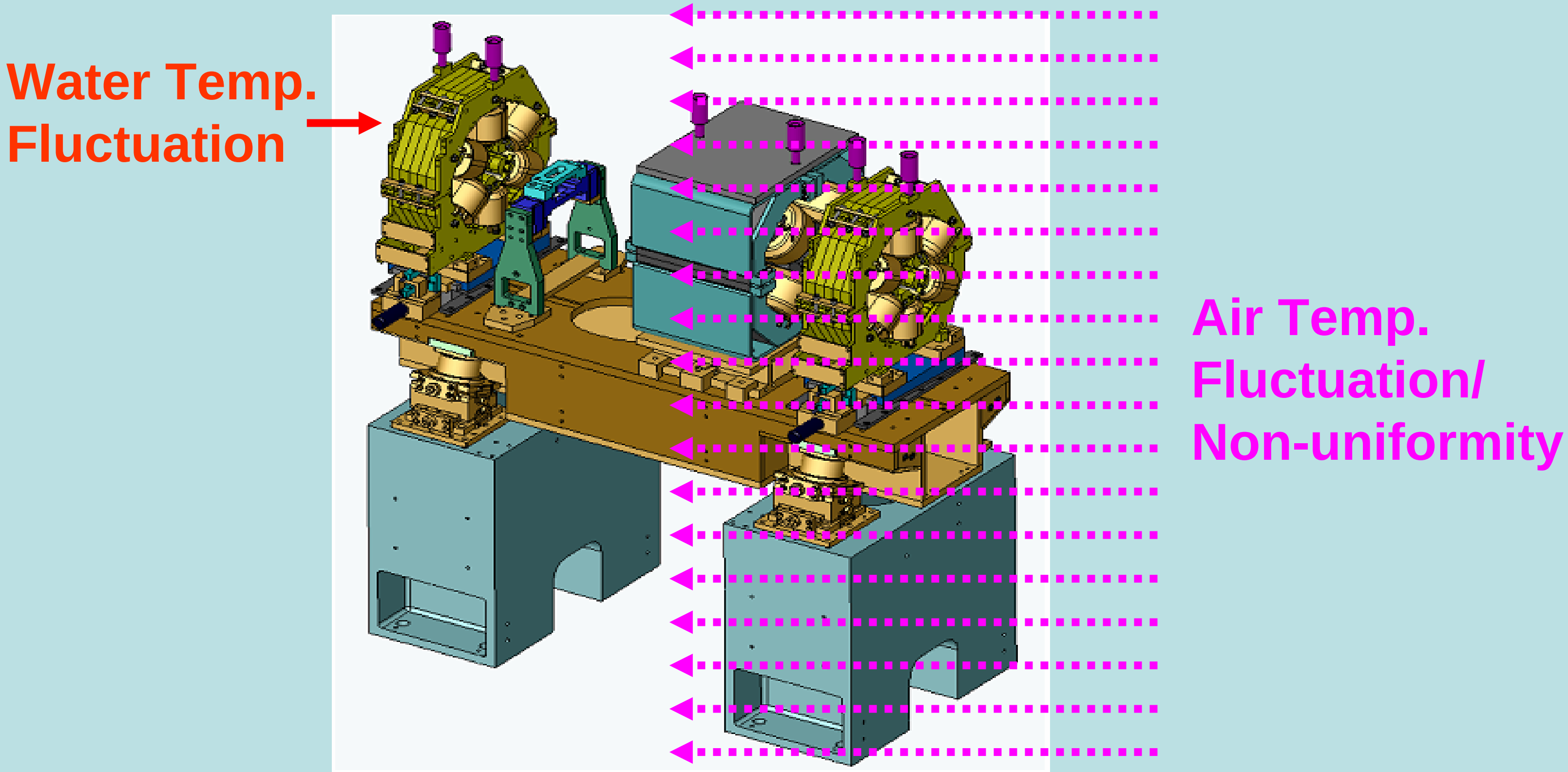
Stiffness of the BPM positioning
(Test result: < 0.2 μm)



III. Temperature stabilization

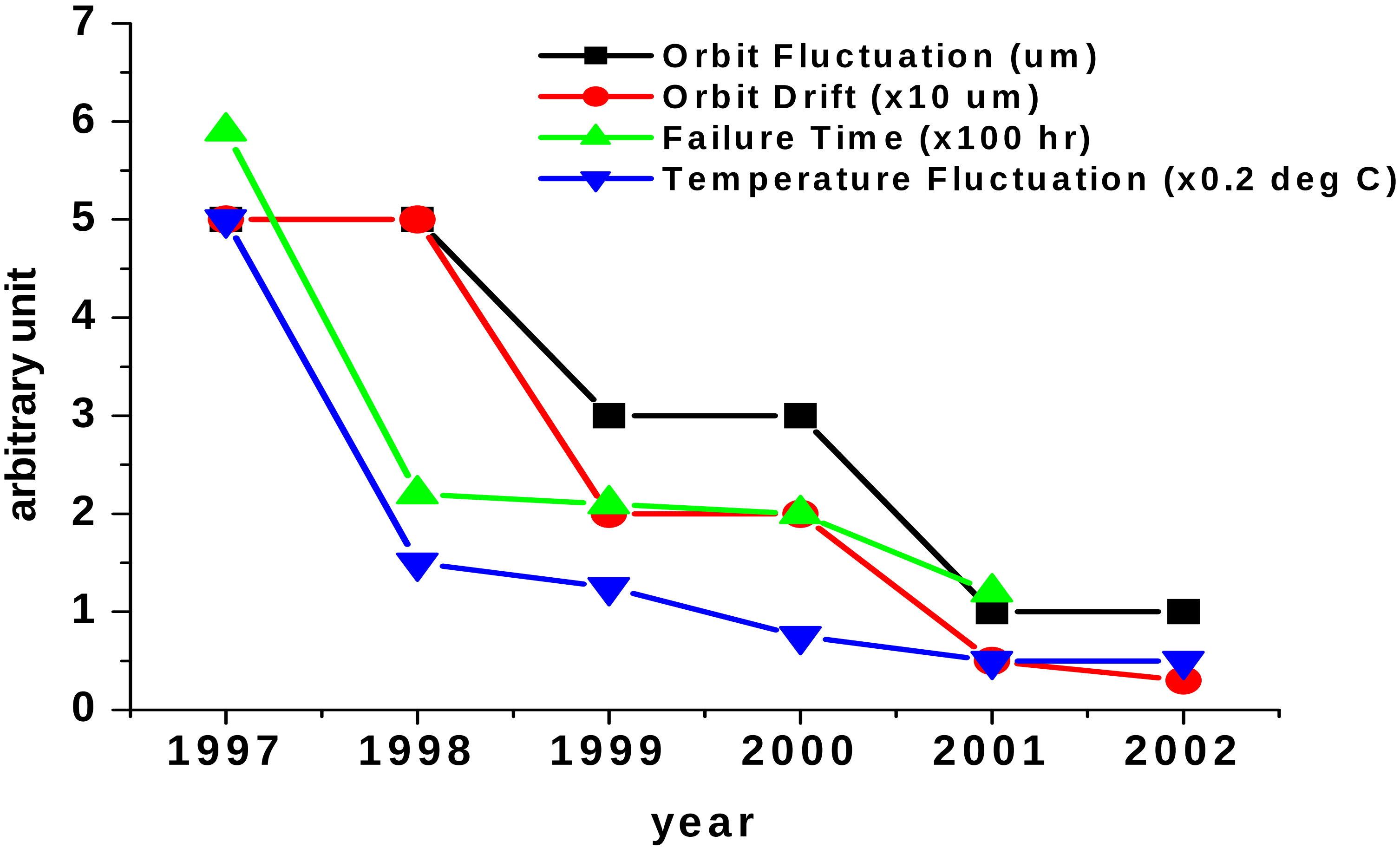
-- Stabilization of heat sources

-- Desensitization of thermo-mechanical effects



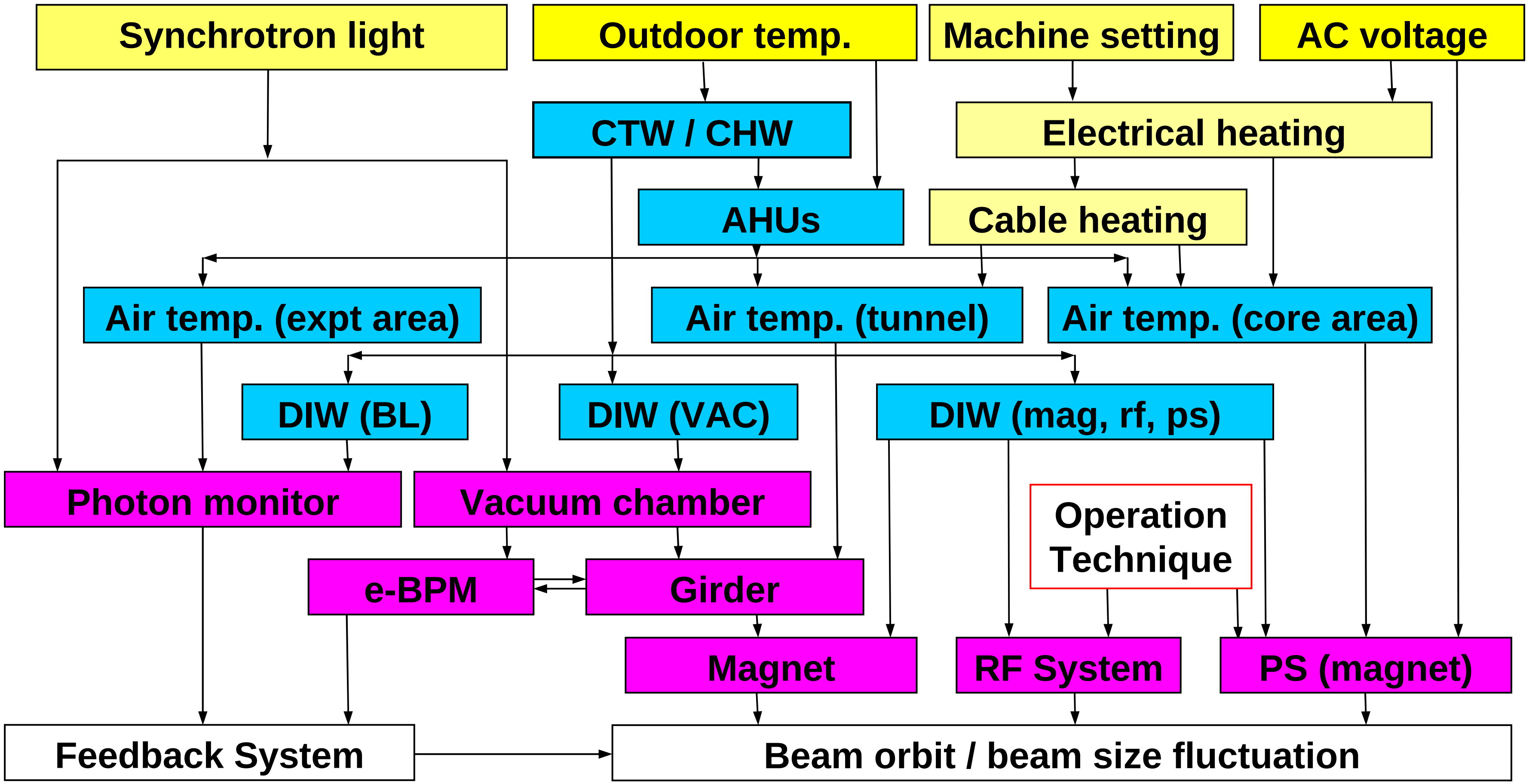
TLS Improvement (I) (1997-2002)

Thermal stability improves
not only the beam stability but also the system reliability.



Temperature Stability

Propagation chart from heat sources to the fluctuations in beam orbit and beam size

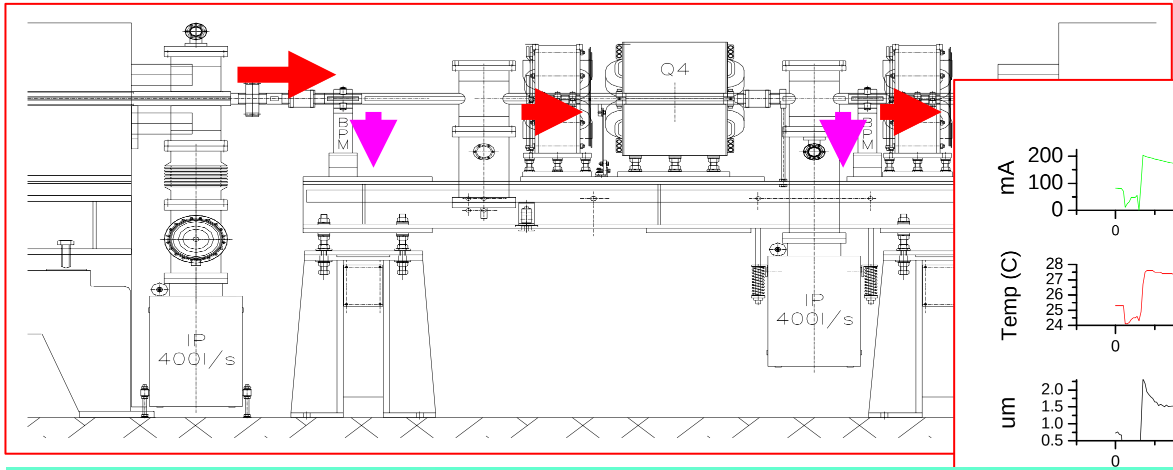


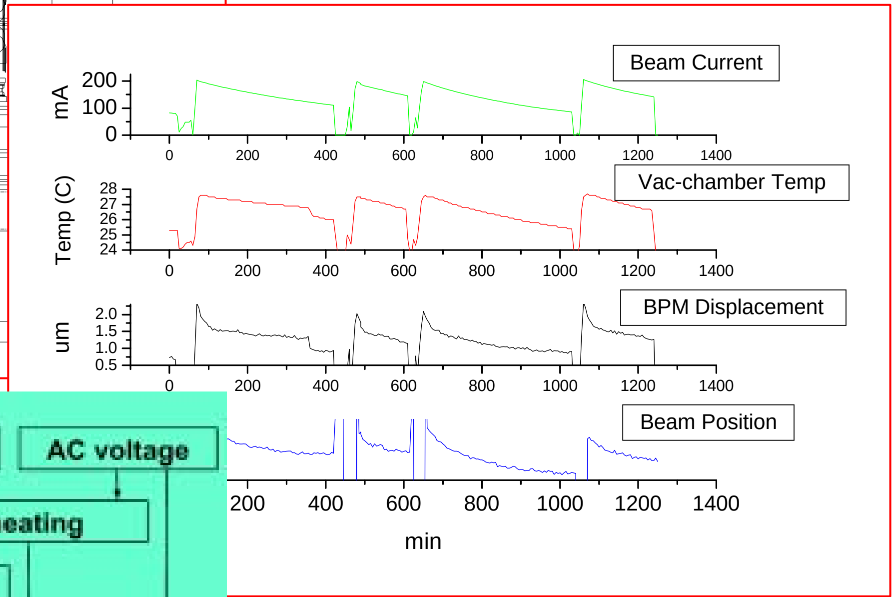
Sources of Noise | Utility System | Accelerator Components

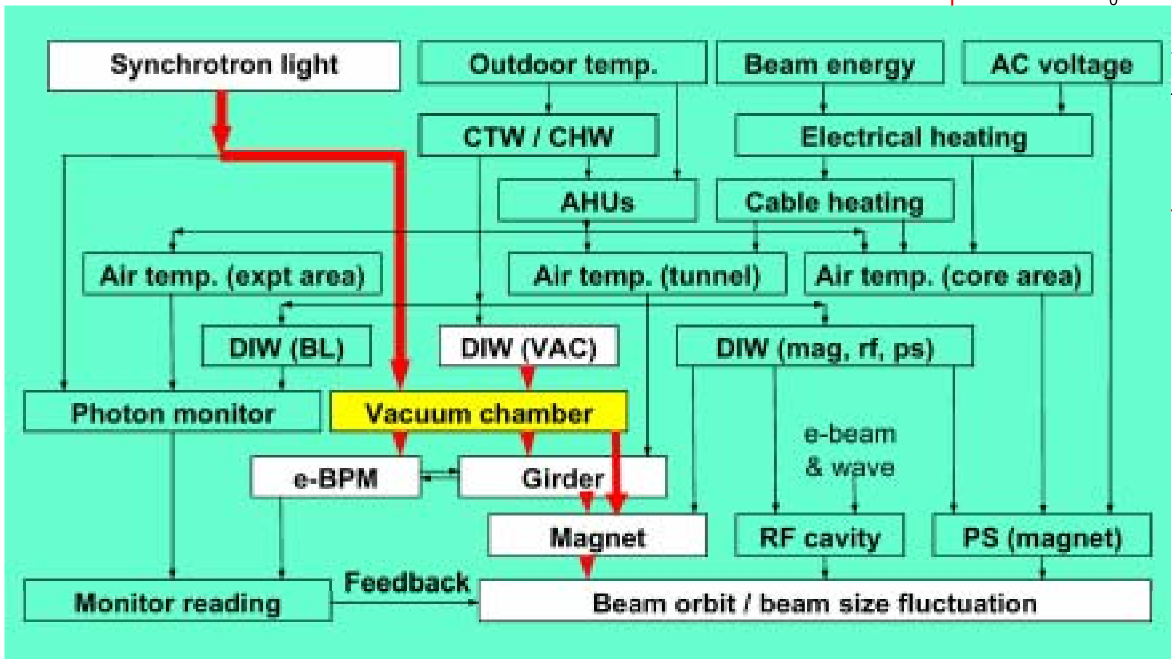
Typical thermo-mechanical effects (TLS)

Sources of disturbance	Time constant	Sensitivity to beam stability	Structure influenced	Solutions
Seasonal temp. variation - *Periodical*	1 y	Circumference ~3mm/y	Floor	RF frequency regulation
Tunnel warming following a long shut down - *Transient*	1w		Floor	Wait (or to maintain tunnel temp. during shut down)
Solar irradiation (tunnel air temperature variation) - *Periodical*	1d	20~100μm/℃	Girder expansion ~10 μm/℃ (ver.)	Insulator jacket / air temperature control
Synchrotron light irradiation (current decay) - *Transient*	hours	10-30μm/℃ (~1 μm/℃ to BPM)	Vacuum chamber & BPM displaced ~0.3μm/℃to girder	Top-up injection
Re-injection with energy ramps (temp redistribution) - *Transient*	~1 h	5-50 μm/℃	Mag.- temp. changed (coil heating) Mag-gap~10μm/℃	Full energy injection
Limited capability of the system to control temp. - *Periodical & Transient*	Minute/ seconds	10-30μm/℃	Girder/ vacuum chamber/ magnets/ monitors/RF/PS	Air/water temp. control ± 0.1C rt-RF cavity± 0.01C
Electrical heating (ac voltage fluctuation) - *Random*	Minute/ seconds		Power supply output Air temp fluctuation	Ac regulator or better temp. control

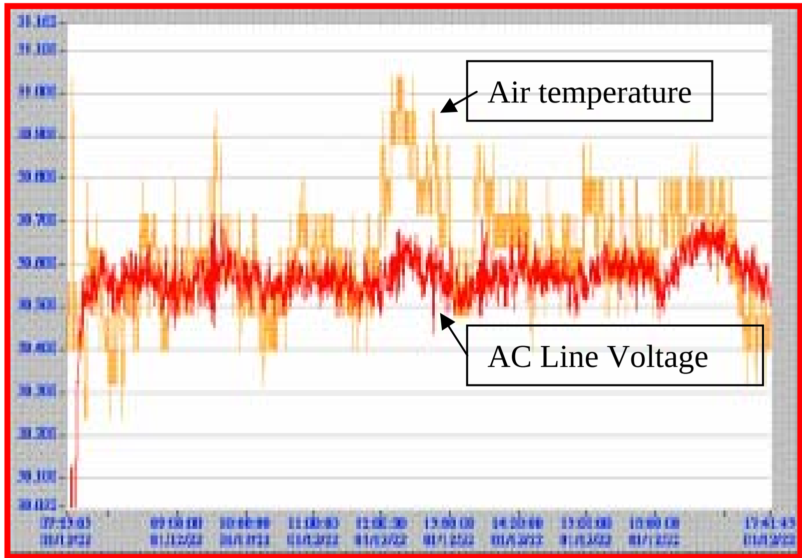
Thermo-mechanical Effects on Vacuum Chamber (TLS)

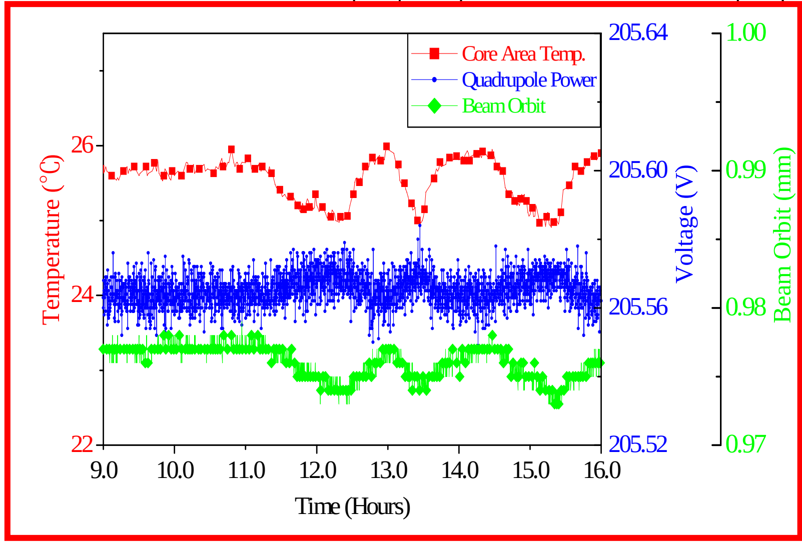


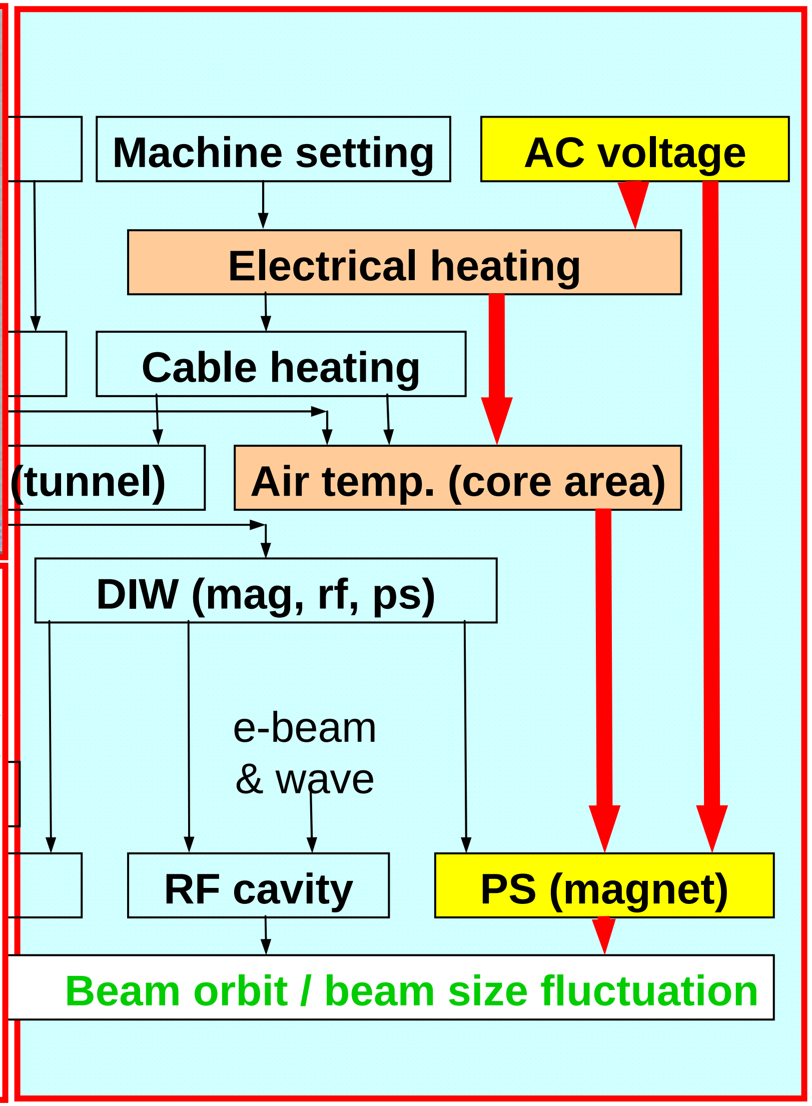




Electrical-Thermo Effect on PS







Water Temperature Stability

- ***Considerations on Temperature Stability Control***

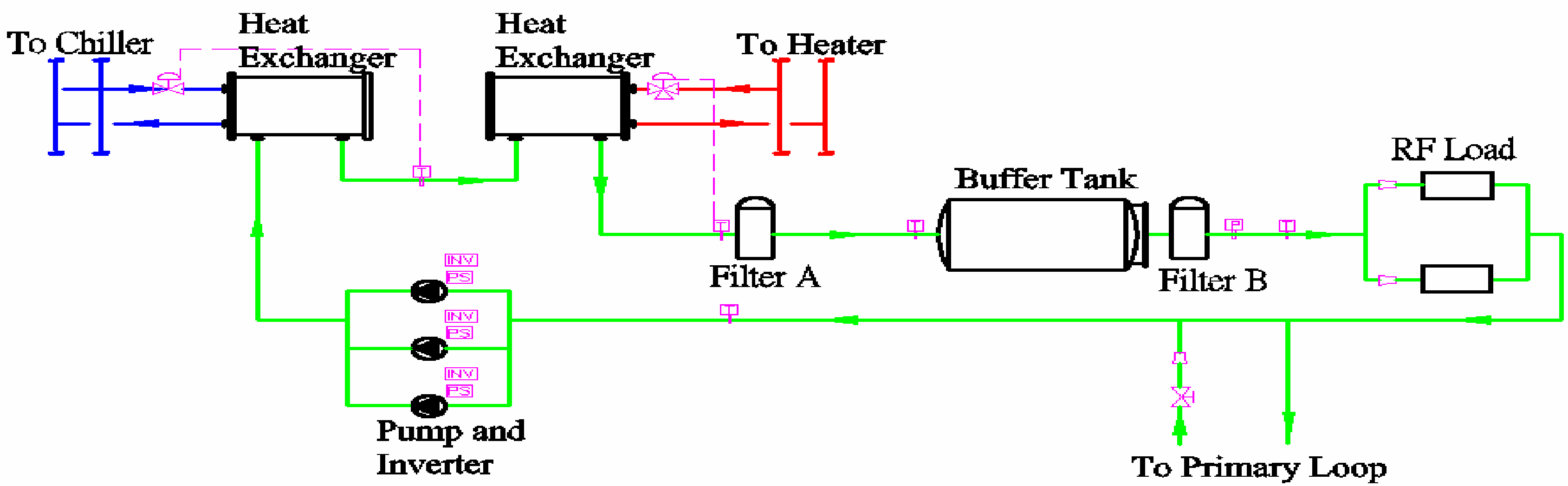
*** Temperature of chilled (& hot) water should be stabilized < ±0.5°C.**

*** Eliminate the nonlinear effects (e.g. backlash) in valves.**

*** Use buffer tank to smooth the temperature variation < ±0.01℃.**

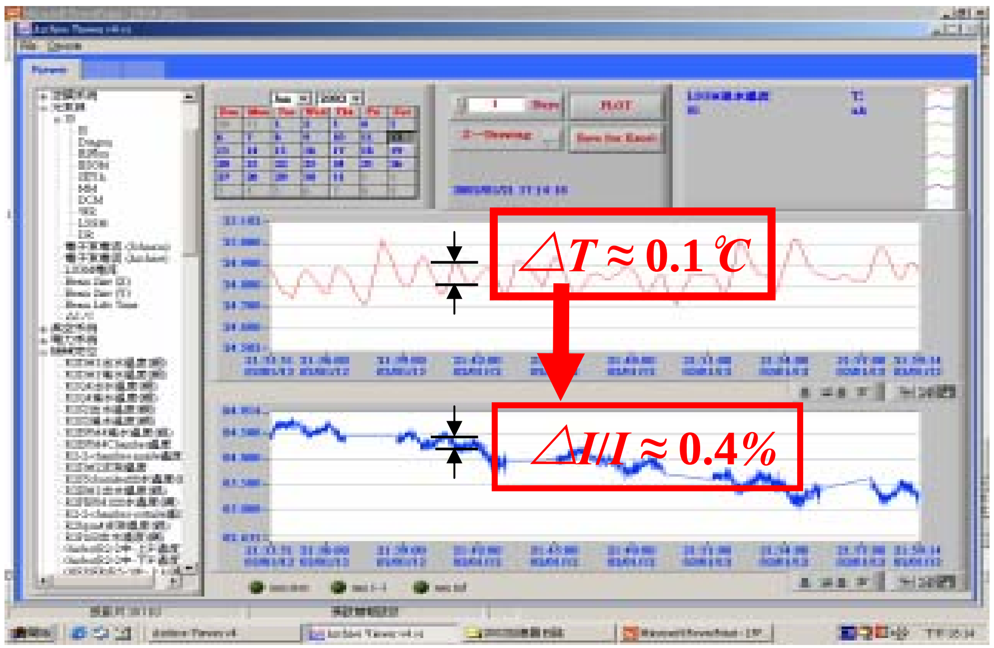
*** High resolution sensor and controller.**

*** Variable frequency controller**

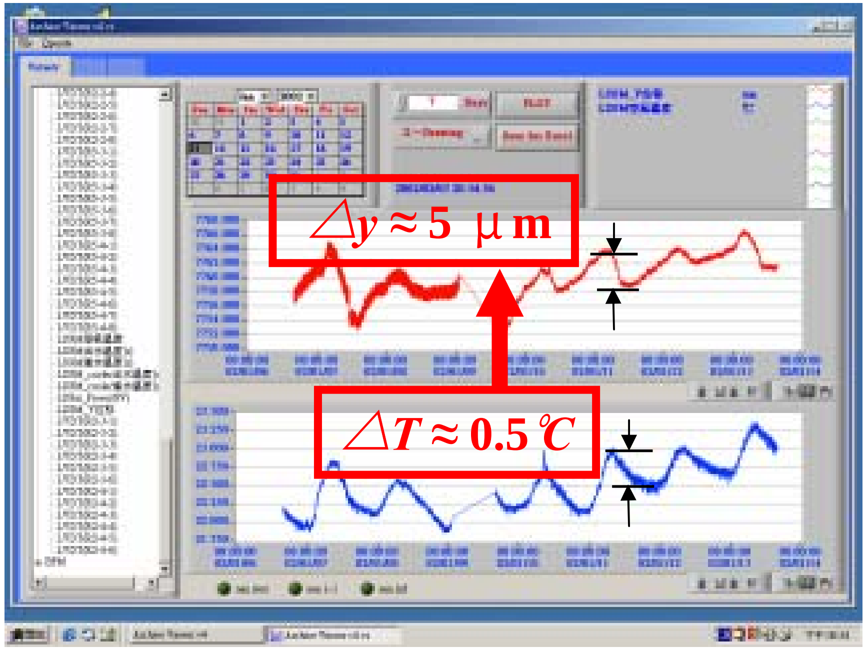


Thermo-mechanical Effects on Photon Intensity (pin hole) Monitor (TLS)

*(**Water** temperature fluctuation)*



*(**Air** temperature fluctuation)*



*For **photon beam monitors,** △I/I < 0.1% :*

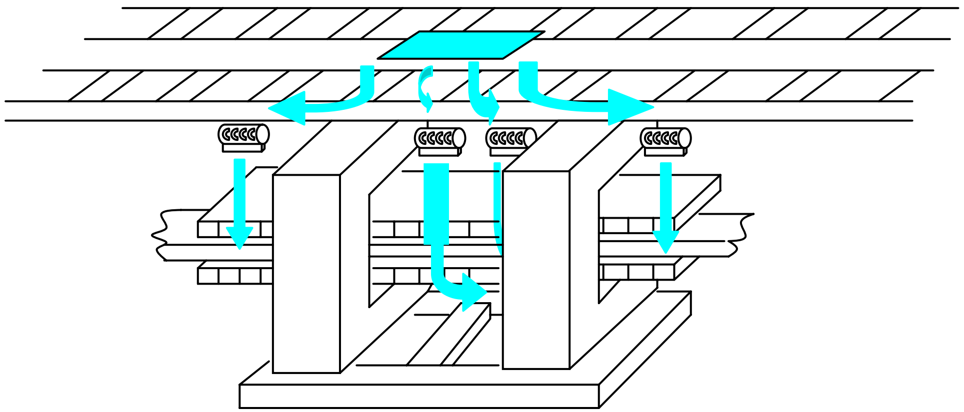
➔ ***△T* ~ 0.01 ℃**

Air Temperature Control

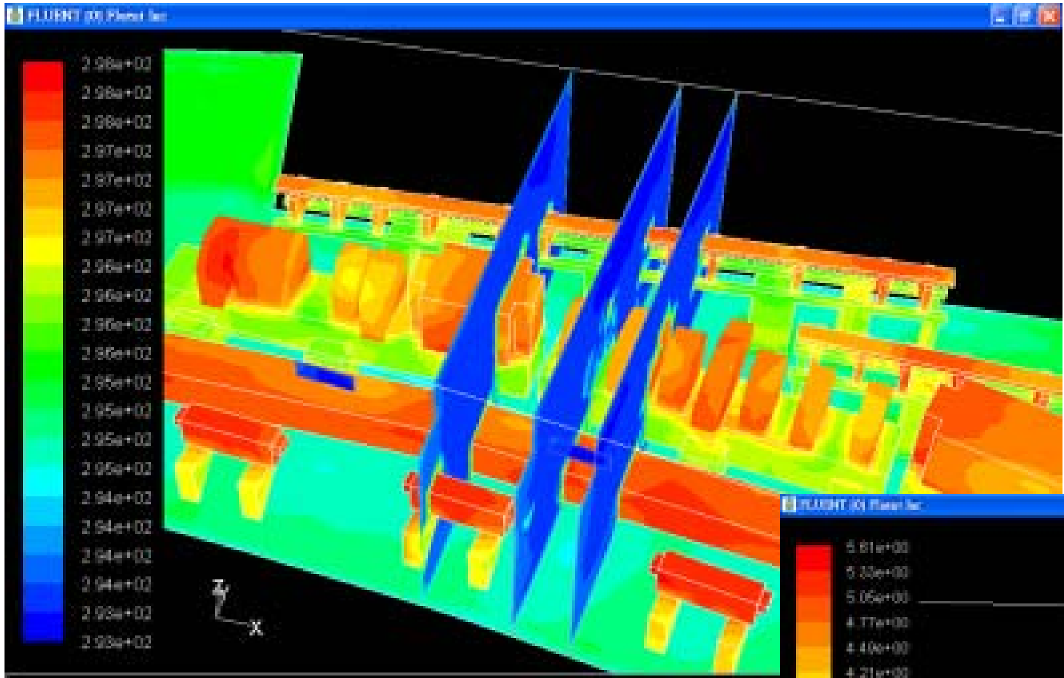
•Considerations on Air Temp. Stability Control

* Temperature of chilled (& hot) water should be stabilized < ±0.5°C.
* Eliminate the nonlinear effects (e.g. backlash) in valves.
* High resolution sensor and controller.
* Flow Pattern controlled
* Thermal Insulation

Flow Pattern controlled

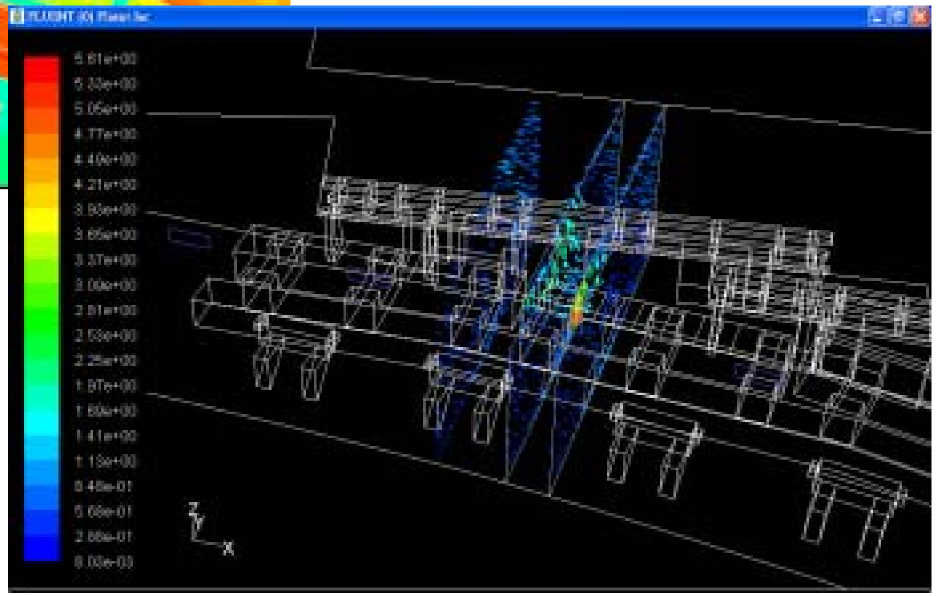


Thermal Insulation



Temperature distribution

Flow pattern

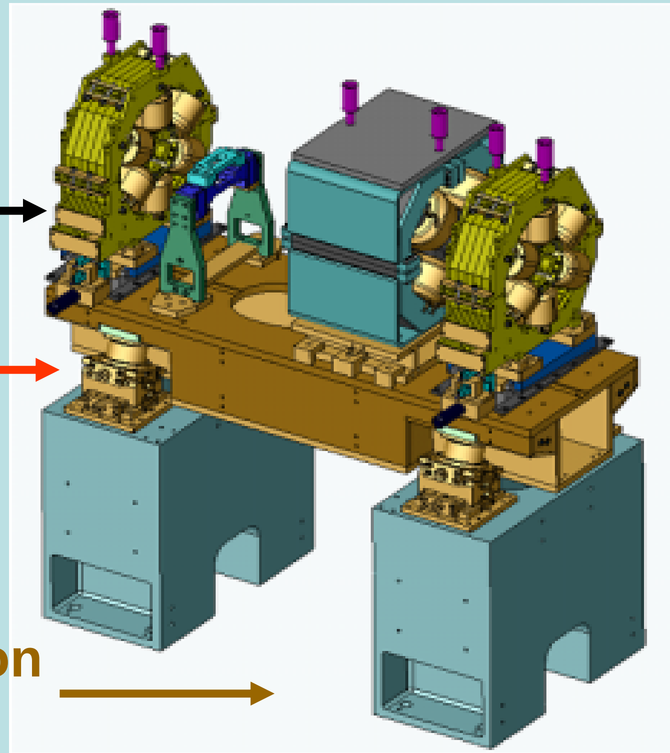


Temperature non-uniformity → Girder/magnet deformed
The effect of temperature fluctuation → to be studied

IV. Vibration suppression

-- Sources of vibration and the suppression

-- Girder and mechanical structures



Typical sources of vibration

Table III. Typical sources of vibration generated naturally, by motor traffic, and by utility equipment, and their related frequencies.

	Sources	Period or frequency
Natural	Earth oscillation	4.5 min, 12min, 20.5min, 54min
	Tide (Ocean wave)	7 sec
	Moon gravitation force (high/low tide)	~12 hour (long wavelength)
	Earthquake	tens Hz
	Wind (ground bending)	0.03-0.1 Hz
	Long-term noise (BG)	$1/f\ 4$
	Ground resonance	~ 3Hz
Traffic	Traffic	~ 4 Hz (hump on road), tens Hz (peak at 30Hz)
Facility Equipment	Pumps, motors	tens Hz (~10 -70 Hz)
	Water vibration	tens Hz (30 – 60 Hz)
	LHe flow	700-1500Hz (45g/s)

Vibration Suppression (I)

Heavy machinery

•**Need dynamically balanced**.

•**Using dampers**

➔ ‘residual’ vibrations still transfer through the ground and/or pipelines to perturb devices.

pipe bellows

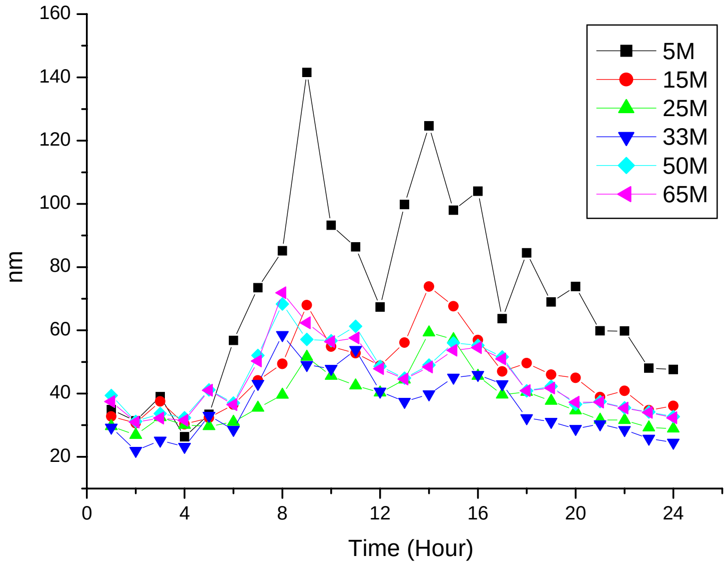
pipe hanger

damper

Vibration Suppression (II)

Further suppression along transfer routes

- **As far away from sensitive components as practicable**
- **Using rubber tubes** (to cut off the transfer route)
- **Appropriate fixture for pipelines**



~4-9 x reduction

	Ring floor	R3BPM5X	R3BPM5Y	R5Q5(Ver.)	R6Q5(Ver.)
Before	3.7-20nm	0.22um	0.34um	27nm	24nm
After	3-12nm	0.1um	0.14um	3.3nm	4.5nm

Vibration Suppression (III)

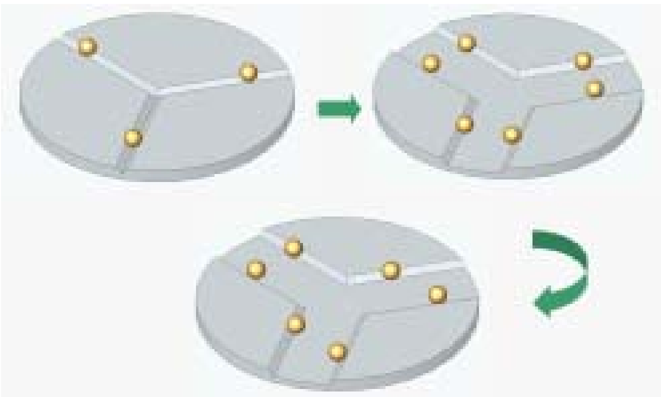
- To decrease the rate of water flow,
- to smooth the piping curvature, and
- to fix the vacuum chamber as rigidly as practicable can diminish the vibration of the vacuum chamber.

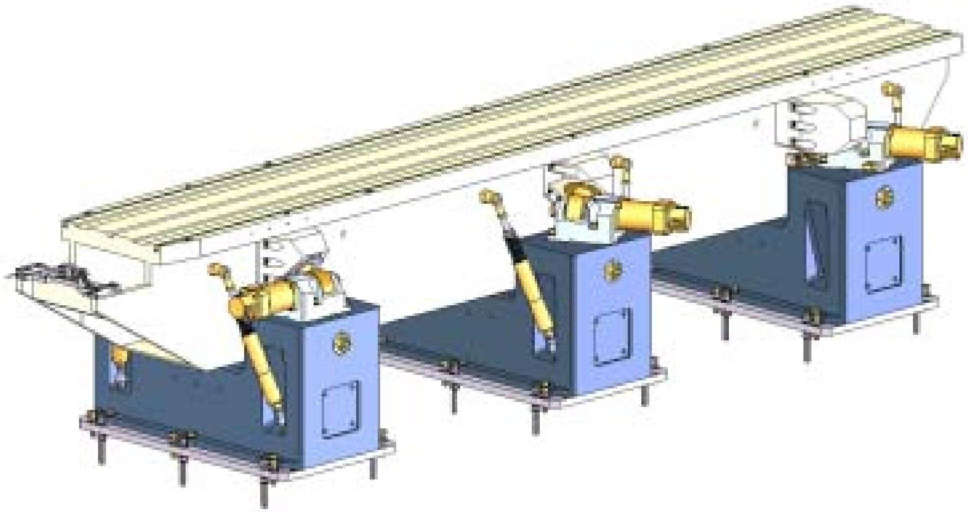
@ Vibration of vacuum chamber (in the magnets)
→ Eddy current effect
→ electron beam influenced
[SPring-8: 30 – 50 Hz vertically, 80 – 100 Hz horizontally]

@ Vertical vibration is more important than horizontal vibration because the size of the vertical beam is much less than of the horizontal beam.

Girder and mechanical structure

Mass → smaller
Center of mass → Lower
Structure → Stiffer
Supporting points → more (but less flexible)





Expanded 3-Groove type kinematics mount. (TPS)

Wedge locking system

Natural frequency improvement

	Y	X	Z
No Lock (1st MAC)	**37.26**	**25.08**	**29.02**
spring	36.62	26.36	30.76
Wedge 0 kg-cm	34.42	26.36	30.76
200kgcm	**43.94**	**32.22**	**38.08**
300kgcm	43.21	32.22	38.08

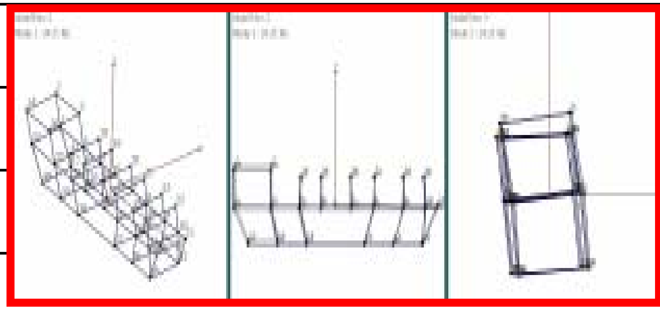
Girder Comparison - 1st natural frequency

Light Source	1st natural frequency (Hz)	Girder Adjusting Method
ESRF	6.8	*Mover*
APS	10.5	"Fixed"
SLS	15.5	*Mover* - 5 degree (2 pedestals)
SPEAR III	15.5	
Diamond	16.3	*Mover* - 5 degree (2 pedestals)
DESY (ALBA?)	15~16	
SSRF	23	"Fixed"
SOLEIL	45	"Fixed" 3 jacks support + 4 **locking system**
TPS (Prototype)	**39 (V)/ 30 (H)**	*Mover* - 6 degree (3 pedestals) (+ **locking system**)

Locking system is effective to increase the natural frequency.

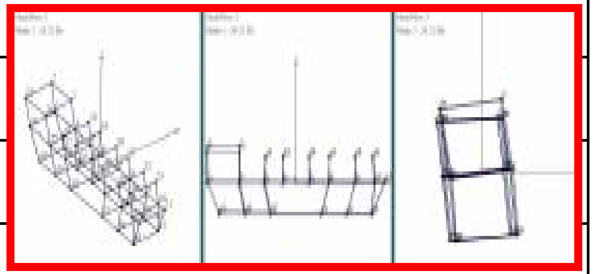
Vibration mode measurements
(< 60 Hz, before improvement)

Mode	Frequency (Hz)	Girder/magnet vibration mode
1	24.21	Roll and yaw
2	28.70	Z direction
3	30.98	yaw
4	32.87	pitch
5	35.61	Y direction
6	41.11	roll, dipole swing
7	44.12	Q1, X&Z direction
8	51.45	Q4, X&Z direction
9	60.18	Q5 and Q6, X&Z direction



Vibration mode measurements (after improvement)

Mode	Frequency (Hz)	Girder/magnet vibration mode
1	29.65	G2_Roll
2	35.31	G2_Yaw
3	39.32	G2_Z-translation
4	52.86	Q6_Z-tanslation
5	53.84	G2_yaw magnets swing
6	56.02	G2_yaw Q4_roll Q6_Z-translation
7	56.97	Q6_Z-tanslation
8	60.06	Q4_roll Q6_Z-translation
9	62.03	Q3_Z-translation Q5_Z-translation Q6_Z-translation



V. Summary

- Detailed studies have been conducted in many laboratories of low-emittance engineering. Significant improvements have been achieved in fine positioning, temperature stabilization and vibration suppression.

- Essentials for a low-emittance synchrotron light source:

  1-a) precise positioning of major components,
  1-b) protecting the position of major components from perturbation,
  2-a) stabilizing the sources of heat,
  2-b) decreasing the sensitivity in each route of transfer from the heat source to the fluctuation of the electron beam,
  3-a) stabilizing the sources of vibration, such as those generated from motor traffic, utility equipment and pipelines,
  3-b) suppressing vibrations along the transfer route from a source to a sensitive device of the light source, and
  4) designing and fabricating a girder less sensitive to sources of vibration

- Improved technologies in positioning, stabilization of temperature and suppression of vibration for the purpose of nanometer stabilization are foreseen challenges.